PTC Thermistors

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1. GENERAL

Positive Temperature Coefficient (PTC) thermistors exhibit a high positive temperature coefficient of resistance. They differ from Negative Temperature Coefficient (NTC) thermistors in the following manner:

1. The temperature coefficient of a PTC is positive only between certain temperatures. Outside this range, the temperature coefficient is either zero or negative.

2. The absolute value of the temperature coefficient of PTC thermistors is much higher than that of NTC thermistors.

PTC thermistors are used in a variety of applications, including current limiting, temperature sensing, degaussing and for protection against overheating in equipment such as electric motors. They may also be used in level indicators, time delay devices, thermostats, and as compensation resistors.

For further details, refer to the 'Applications' section.

2. ELECTRICAL COMPOSITION

PTC thermistors are prepared from BaTiO3, by a similar method to that used in the preparation of NTC thermistors, using solid solutions of BaTiO3. Extra electrons on the Ti ions are created by introducing foreign ions having a different valency. Use of these compounds allows two alternatives for preparation:

- 1. Substitution of trivalent ions such as La 3+ or Bi 3+ for Ba 3+, or
- 2. Substitution of pentavalent ions such as Sb 5+ or Nb 5+ for Ti.

Both methods give identical results. If prepared in the absence of oxygen, these semiconductors exhibit a weak temperature coefficient of resistance. A strong positive coefficient is obtained by firing the ceramic samples in an oxygen rich atmosphere. This is achieved by penetrating the pores and crystal boundaries with oxygen during the cooling period following the firing process. The oxygen atoms, which have been absorbed on the crystal surfaces, attract electrons from a thin zone of the semiconducting crystals. This forms electrical potential barriers consisting of a negative surface charge with, on both sides, thin layers having a positive space charge resulting from the now, uncompensated, foreign ions. These barriers cause an extra resistance in the thermistor, exhibited by the formula:

Rb
$$\alpha$$
 (e^{eVb/kT})/a (α = directly proportional to)

where, 'a' represents the size of the crystallites, thus 1/a is the number of barriers per unit length of the thermistor, and Vb represents the potential of the barriers. Since Vb is inversely proportional to the value of the dielectric constant of the crystals, Rb is extremely sensitive to variations in the dielectric constant. Such variation in the dielectric constant is a special property of materials having a ferroelectric nature as can be found in the compound BaTiO3 and its solid solutions. If their ferroelectric Curie temperature (B) is exceeded, the relative dielectric constant decreases with the temperature increase in accordance with the relationship shown overleaf:

$$\epsilon_r = C/(T - \theta)$$

where C has an approximate value of 10⁵ K. As a result, the resistivity increases sharply just above the Curie temperature. Below the Curie temperature, the barriers are weak or absent, partly as a result of the high effective dielectric constant of BaTiO3 in strong fields, and partly as a result of the spontaneous polarization of the crystals which may compensate the boundary changes.

The electrons are captured at the boundaries and gradually liberated in proportion with the increase in body temperature of the PTC with respect to its switching temperature, causing the potential barriers to decrease in strength. This means that the PTC loses its properties and may eventually respond in a similar fashion to a NTC if the temperature becomes too high. The applications of a PTC are, therefore, restricted by a certain temperature limit.

Since the PTC effect is caused by crystal boundary barriers, the extra resistance Rb is shunted by a high parallel capacitance Cb. This leads to frequency dependence of an extra impedance Zb up to 5 MHz. The characteristic properties described in the following paragraphs are thus restricted to this frequency range.

3. ELECTRICAL PROPERTIES

Resistance/temperature characteristics

Figure 1 shows a comparison of typical resistance/temperature characteristic curves for PTC and NTC thermistors.



Voltage/current characteristics

Static voltage/current characteristics display the current limiting ability of PTC thermistors. Up to a certain value of voltage, the V/I characteristics follow Ohm's law, but the resistance is increased when the current passing through the PTC causes it to heat up and reach its switching temperature (see Fig.2). The V/I characteristic is dependent on ambient temperature and the heat transfer coefficient with respect to ambient temperature.

As can be seen from Fig.2, the characteristics are plotted on a linear scale, however it is more common to plot the characteristics on a logarithmic scale (see Fig.3), since it gives a clearer view of the overall response.

It is possible to calculate the peak of the V/I characteristic accurately if the R/T characteristic and the dissipation factor (D) are known.

The dissipation factor (measured in mW/°C) is the ratio at a specified ambient temperature of a change in power dissipation in a thermistor, to the resultant body temperature change. By convention, the dissipation factor can only be calculated at the peak of the V/I curve, also making use of the corresponding point on the R/T characteristic.



Fig.2 Voltage/current characteristics of a PTC thermistor plotted on a linear scale, using ambient temperature as the parameter.

By definition:

- the electrical power injected in the PTC thermistor is:

P=I²⋅R

where R is the resistance (before switching) at Tamb

- the power dissipated by the ceramic is given by:

D.(Ts - Tamb)

where Ts is the switch temperature and Tamb is the ambient temperature, then,

 $I^2 \cdot R = D \cdot (Ts - Tamb)$

Note: This equation is only valid for temperature having a value less than Ts.



The trip current (It) is defined as the minimum guaranteed current which will cause the thermistor to switch, and can be calculated using the formula:

$$I_t^2 \cdot R = D \cdot [Ts - (Tamb + \omega)]$$
, hence:

It =
$$\{D \cdot [Ts - (Tamb + \omega)]/R\}^{0.5}$$

where R is the PTC resistance at Tamb.

Normally, a security margin of + ω °C is maintained in order to assure thermistor switching due to inaccuracies in the values of Ts and Tamb.

The non-trip current (I_{nt}) is defined as the guaranteed maximum current at which the thermistor will not switch, and is given by:

 $I_{nt}^{2} \cdot R = D \cdot [Ts - (Tamb - \omega)]$, hence:

It =
$$\{D \cdot [Ts - (Tamb - \omega)]/R\}^{0.5}$$

A security margin of - ω °C is maintained to ensure that the thermistor will not switch.

The slope of the R/T characteristic is designated by a series of production parameters. The relationship between R/T and V/I characteristics is demonstrated clearly in Figs 4 and 5.



Fig. 4 R/T characteristics of PTC thermistors 2322-660-91006 and –91009.



Fig.5 Typical I/V characteristics of PTC thermistors 2322-660-91006 and –91009 measured in still air at 25 °C.

PTC thermistors in series with a load

It can be shown from the V/I characteristics that, because of the non-linearity of the PTC curve, three working points are possible when a load R is connected in series with a PTC (see Fig.6). The characteristics of the load is a straight line intersecting the voltage co-ordinates at the supply voltage, Va. P1 and P2 are stable working points; P3 is unstable.

When the voltage Va is applied to the series connection, equilibrium is reached at P1, a point with a relatively high current. P2 can only be reached when the peak of the V/I curve lies below the load characteristic. This may happen in a number of cases:

- 1. Va increases, see Fig.7
- 2. the ambient temperature increases, see Fig.8
- 3. the load resistance decreases, see Fig.9

It can therefore be seen that the PTC thermistor provides excellent protection properties, limiting the load to a safe value if the supply voltage, temperature or current exceeds a critical value.



Fig.6 PTC thermistor in series with a load showing the possible working points.



Resetting resistance

When the PTC thermistor is switched i.e. its temperature rises above the switching temperature Ts, it can only return from P2 to P1 if the load line lies below the V/I characteristic curve. This means that:

1. either the supply voltage Va decreases (at constant load resistance), see Fig.10, or 2. the load resistance increases (at constant voltage), see Fig.11,

Fig.10 PTC thermistor in series with a load showing the influence of a decrease in supply voltage Va.

Fig.11 PTC thermistor in series with a load showing the influence of increased load resistance. Note: When the temperature of the PTC thermistor is greater than Ts (i.e. the thermistor is in its tripped state), it will heat up causing the ambient temperature to increase (as shown in Fig.B). This must be taken into account when calculating the value of load resistance (i.e. the resistance of the PTC).

Current/time characteristics

If a PTC thermistor is connected in series with a resistance of such a value that the peak of the V/I curve lies under the load line, the PTC will heat up until the stable working point (P2) is reached (see Fig.I2). The time taken to rach this point is dependent on the value of load R (see Fig.I3) and the ambient temperature.

Temperature coefficient (a)

1 dR The temperature coefficient a = R dT

For R-T curves plotted on a log R-T scale: d In R 1 d log R a= - . dT 0.4343 dT In the data sheets, the maximum temperature

In the data sheets, the maximum temperature coefficient (a) is given; this is measured at the point of inflection of the log R-lin T characteristic, i.e. the point where d2log R/dT~ = 0 (see Fig.15I.

When one resistance decade is taken (R2 = 10 R1/, the formula becomes:

100 1 0.4343 X T2 - T1 °~°/K

Trip time

The trip, or response time is defined as the time taken for the PTC thermistor to reach its switching temperature at a constant voltage. This time period is also equal to the time taken for the current to be reduced by a factor of 2.

The trip time Sts) can be calculated using the formula:

h . v . (Ts - Tamb)

It2 . R25 - D(Ts - Tamb)

where: - v is the volume ot the ceramic in mm3 - R25 is the resistance at 25 oC

- It is the trip current

- the specific heat of the ceramic $h = 2.5 \times 10'3 \text{ J/oC/mm3}$

Thermal time constant (r)

The thermal time constant is the time required for a thermistor to convert 63.2% of the total difference between its initial and final body temperature when subjected to a step function change in temperature under zero power conditions.

Fig.I6 Thermal time constant.

Voltage dependence (VDR effect)

PTC thermistors exhibit voltage dependence. The higher the voltage applied, the more the R/T curve deviates from the R/T characteristic at 'zero voltage' (measured at a negligibly small voltage). This voltage dependency can be demonstrated by applying a pulsed voltage to the thermistor and then measuring the R/T characteristic.

This effect can be explained with the aid of a parallel connection of an 'ideal PTC', having no voltage dependence, and an 'ideal VDR'.